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Plant Life Extension programs - useful resources for preservation and amplification of Nuclear Power Plants efficiency

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Abstract. Plant Life Management (PLIM) is now usually taken to mean those many activities which are to do with the normal operational management of a nuclear power plant to maintain its 'good condition' and to enable operators or Owner(s) to meet the plant's intended amortisation period, operational life or design operational life. That is, it is to do with existing planned Plant Operational or Service Life assurance and not necessarily to do with meeting an additional period or extended operation time in excess of that intended at the design or evaluation stage, which is usually known as Plant Life Extension (PLEX).
The paper presents considerations regarding the ageing management of the NPP's key components, Plant Life Management (PLIM), refurbishment as activity strictly necessary for Plant Life Extension, and the Romanian refurbishment program as part of PLIM from Cernavoda CANDU NPP.

Keywords: Plant Life Management (PLIM), Plant life extension (PLEX), Long Term Operation (LTO), refurbishment

1. Introduction

Research and development tasks are needed with the aim to establish clear definitions and objectives for all the programs related to the NPP components lifetime, not only in the long term extrapolation of the component integrity and

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behaviour, but also in the development of new management strategies at the plant (PLIM), able to address organisational issues, asset management, human reliability and ageing issues, all at once, in a coordinated approach.

Plant life management (PLiM) plan is an action programme whose aim is to achieve the original design life without safety deterioration and to keep the possibility of the nuclear power plant license renewal open, for its LTO. In recent times, this concept applies to CANDU technology reactors; but in the past, it was referred to as ageing management plan (AMP), with a similar methodology. A PLiM plan must integrate and, if necessary, complement all the activities related to the assessment and control of the ageing mechanisms affecting passive and long term Systems, Structures and Components (SSCs) relevant to safety.

Ageing management programmes (AMPs) represent a structured set of activities oriented to the surveillance, control and mitigation of ageing effects which affect the SSCs comprised in the ageing management process scope. Management programmes are based on different predictive, preventive and corrective maintenance practices, environmental qualification programmes, periodic testing and surveillance of technical specifications (TS), in service inspection programmes, erosion-corrosion programmes, etc., as well as any other specific activity which might be performed at the nuclear power plant with the same purposes.

Periodic safety review (PSR) means a systematic safety reassessment of a nuclear power plant performed at regular intervals (usually every 10 years), to determine the impact of the accumulative effects of ageing, modifications, operative experience, technical developments and site aspects on the facility, and whose aim is to guarantee a high safety level throughout the operating life of the facility.

Design life consists in the period of time during which a nuclear power plant or component is expected to behave according to the technical specifications to which it was built or manufactured. In most western design nuclear power plants, part of the studies which support the plant safety assessment have been performed with a 30 to 40 years design life hypothesis; for example, those components which cannot be replaced, such as the reactor vessel or the containment building, are the reason why a nuclear power plant's design life is usually considered to be of 30 to 40 years.

Lifetime is defined as the period of time from initial operation to final withdrawal from service of a structure, system or component. It may also be referred to as service life. Lifetime may be longer than design life, provided that actual operating conditions have been less severe than the supposed design ones. The remaining life margin of a SSCs can be determined by the comparison between the design conditions with the actual operating conditions.

Long term operation (LTO) represents the continued operation of the nuclear power plant maintaining an acceptable safety level, beyond its design life, after performing a safety assessment which assures that safety requirements applicable to its SSCs are met, by implementing the necessary improvements. It is also referred to as life extension. The safety assessment supporting the LTO of the nuclear power plant shall include, along with the ageing management review for the new period, the safety analysis review considering a lifetime longer than the design life of the nuclear power plant. Plant Life Extension (PLEX), often called Long Term Operation program (LTO), is a process often implemented in the nuclear Countries, due to the ageing of the plant fleets and the need to secure important energy sources combined with investment protection.

Plant life extension (PLEX) means the extension of the safe operating life of a nuclear power plant beyond its design life. This involves either the *replacement* or *refurbishment* of main components or *substantial modifications*, or both, [1] ÷ [8].

2. Ageing management – essential part of NPP' Plant life extension program

In general, ageing management is addressed in procedures for maintenance, surveillance, in service inspection programme (MS&I), etc. as one of the irreversible physical degradation processes, which could lead to failure. The operating experience shows that active and short-lived (Systems, Structures and Components (SSC) are in general addressed by existing maintenance programmes. Conversely, the performance and safety margins of the passive longlived SSC are assumed to be guaranteed by design. However, the analysis of the operating experience showed that unforeseen ageing phenomena may occur either because of shortcomings in design, manufacturing or by operating errors. Therefore the implementation of an (Ageing Management Program) AMP and a predictive MS&I programme is definitely a condition for the operation within the limits of design or licensed lifetime and is a precondition for an LTO as well.

A major stressor in an ageing structure is time itself. Fig.1 were presents Ageing factors, basic ageing mechanisms and possible consequences [9].

The ageing management is intended to provide a crosscutting connection among all maintenance and inspection activities carried out on active components also, to provide a unified understanding and treatment of the degradation phenomena. In conclusion, both the AMP and MS&I programmes could be accepted if the following actions are completed: programme scope is defined, preventive actions are developed, parameters to be monitored or inspected are detected, detection of ageing effects is ensured, monitoring and trending is performed, acceptance criteria are defined, corrective actions confirmation process are defined, administrative control is fixed and operating experience of the programme is considered.

Some of these attributes are inter-related. Particularly the frequency, the rending and the number of locations to be monitored may reflect the operating experience from past operation.

There are a large number of degradation mechanisms operating in the major components of NPP. Potential ageing mechanisms and the resulting degradation effects on components are shown in Fig. 2 [9].

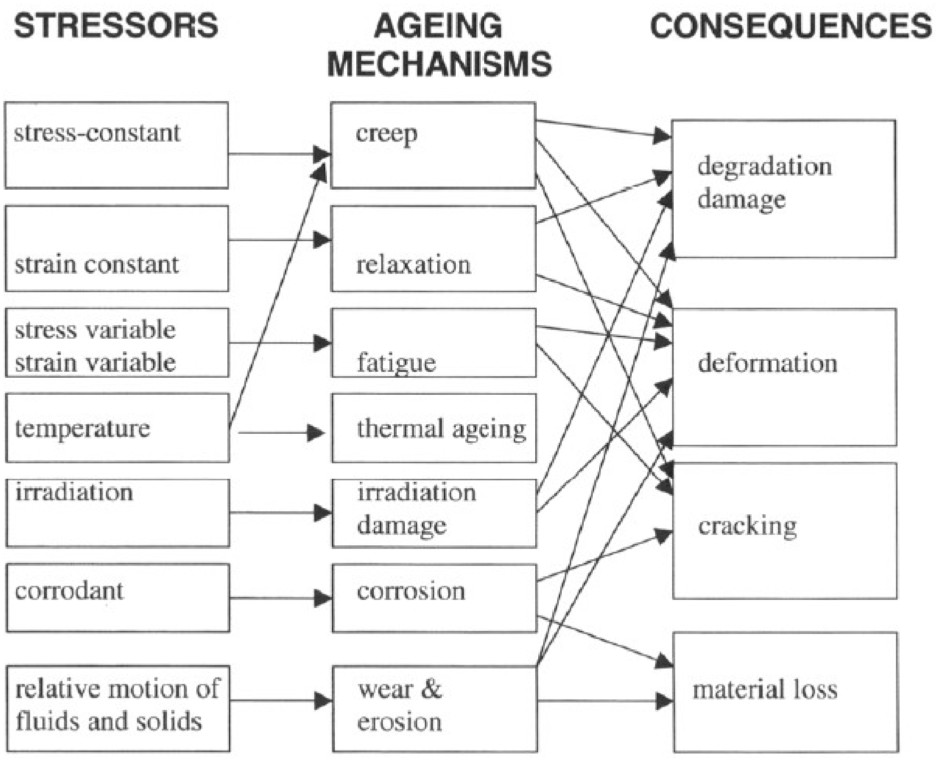

Fig. 1. Ageing factors, basic ageing mechanisms and possible consequences.

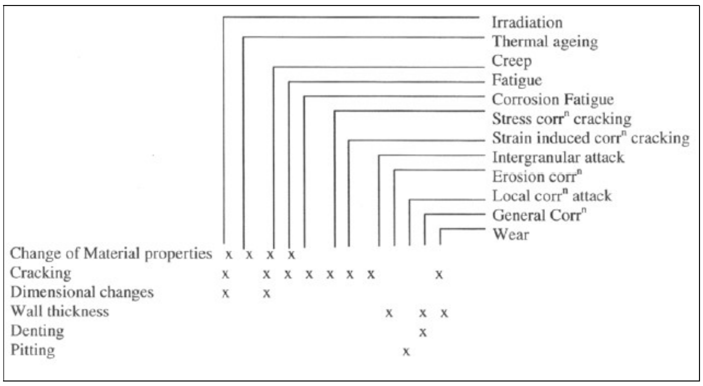

Fig. 2. Potential ageing mechanisms and resulting effects on components.

Fig. 3 presents the principal activities (elements) necessary for CANDU Plant Life Management, [10].

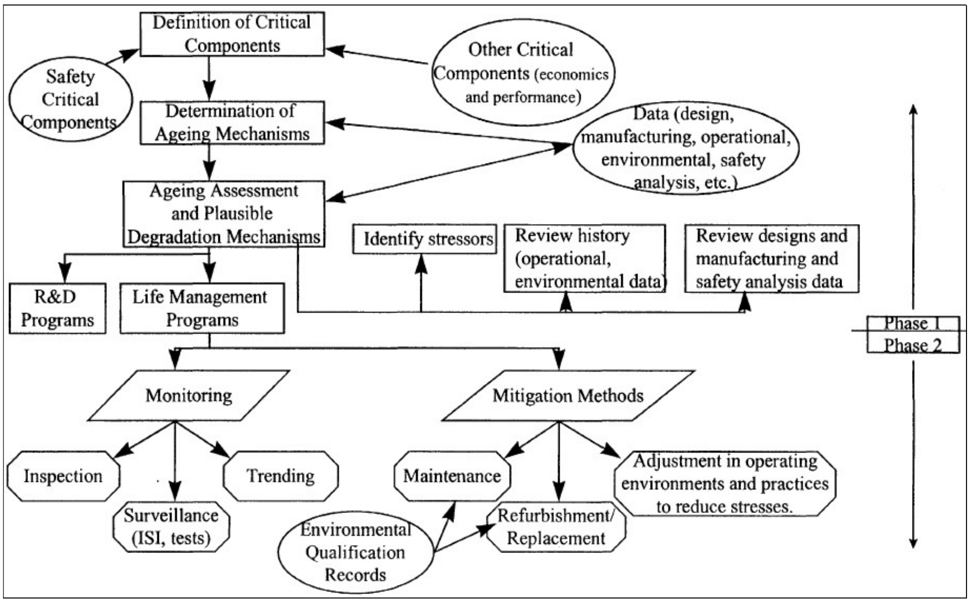

Fig. 3. Elements of CANDU Plant Life Management.

For a CANDU NPP they were identified 16 key components and 9 critical components as follows:

Key components of a CANDU NPP (16):

1. Fuel Channels
2. Steam generators and their internals components
3. Calandria vessel
4. Reactor headers
5. Primary Heat Transport piping pressuriser
6. General nuclear piping
7. Calandria supports
8. Secondary piping
9. Building
10. Calandria vault and end shield system
11. Cables (power, control and instrumentation)
12. Reactor building
13. Turbines
14. Generator
15. Cooling Water intake structure
16. Spent fuel bay/liner

Critical components of a CANDU NPP (9):

1. Fuel channel
2. Steam generators
3. Calandria vessel/supports
4. Reactor Headers, Pressuriser, Piping
5. Some Secondary Side piping
6. Cables
7. Civil Containment Structures
8. Turbine/Turbine Generator
9. Cooling Water Intake

Fig. 4 presents an integrated approach to life assurance containing the systematized: CANDU components, the plant life assurance methods and critical factors [11].

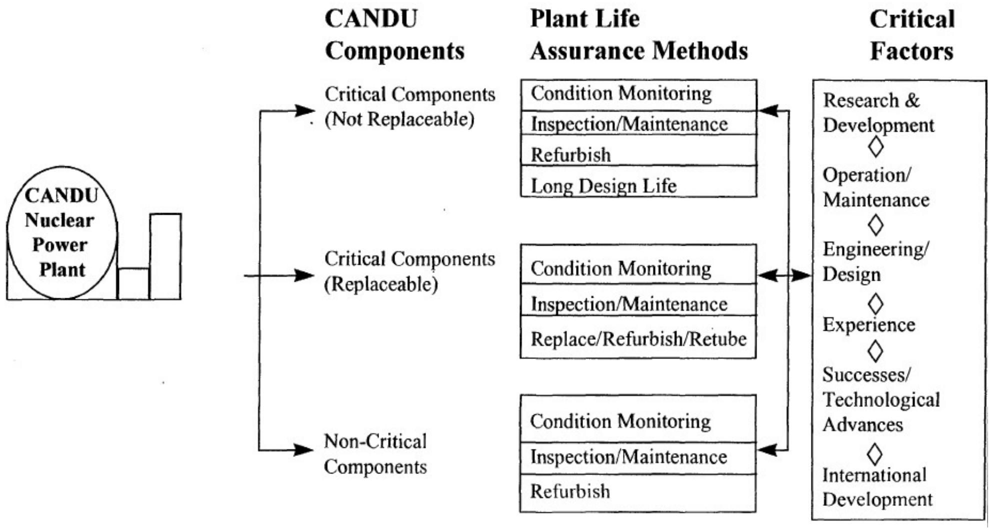

Fig. 4. Integrated approach to Life Assurance.

3. Refurbishment – activity strictly necessary for Plant Life Extension

The 10 steps of NPP refurbishment [12], [13]:
1. shutdown the reactor;
2. remove fuel and heavy water;
3. island the unit;
4. remove feeder pipes and tubes;
5. replace feeder pipes and tubes;
6. other major components;
7. place new fuel in reactor;
8. return reactor to service;
9. return reactor to full power.

Steam generators (SGs) refurbishment

The SG project must be broken down into separate elements of work to be performed throughout refurbishment, [14]÷ [17]. These include:

- ***Primary Side Cleaning*** – mechanical cleaning of magnetite from the inner diameter of the SG tubes;
- ***Secondary Side Cleaning (Waterlancing)*** – cleaning of the outer diameter of tubes at the tubesheet with a combination of high pressure lancing and low pressure/annulus flushing with visual inpections of the tubesheet area;

- ***Access Port Installation*** – allows additional visual inspection locations of SG internals during and post refurbishment. The ports are also required to provide future ability to clean the upper support plates and preheater region through waterlancing or future chemical cleaning, access for foreign material retrieval, and remore inspection of U-bend region and upper supports;
- ***Inspection and Repair*** – is required per SG Life Cycle Management Plan (LCMP). This work includes tube plugging;
- **Divider Plate inspectios, Boiler Open/Close, and Inspection** – primary side divider plate leakage measurements using the acoustic leakage inspections system will be undertaken during the refurbishment outages to compare measurements conducted in previous outages;
- ***Bleed Cooler Inspection and Bundle Replacement*** – in accordance with the Component Condition Assessment (CCA), bleed cooler tube wall thickness measurement will be taken. Based on the resuts, tube plugging may be required. Bleed cooler bundle replacement is contingent on the results of the initial inspection.

Cernavoda NPP refurbishment program

The refurbishment of Cernavoda NPP Unit#1 represents the largest investment project developed exclusively by Nuclearelectrica (SNN). Any nuclear unit has a limited period of operation, established by project. In case of units with CANDU technology, the designed period of operation is of 210,000 hours of operation at nominal power, which at a capacity factor of 80%, is translated by an economical operational exploitation period of approximately 30 years. The main components and structures limiting the period of operation are the fuel channels, feeders and the envelope of the nuclear reactor.

Given the major costs implied by performing such new large dimension production units, by using nuclear technology, the refurbishment technology is attractive for the owner of a nuclear unit. the main advantage of such option is that, at the end of the refurbishment, the owner will be in the possession of a nuclear unit capable to operate on project parameters for another cycle of life (25 – 30 years), for costs situated around 40% of the ones which might be implied by building a similar new objective. In addition, the refurbishment is more beneficial than building a new capacity through the fact that the period necessary for effective refurbishment works is significantly shorter, estimated, based on information available starting right now, in between 24 and 30 months.

Extension of operating hours Unit#1 from Cernavoda NPP was commissioned on December 2nd, 1996. According to the evaluations, due to the fact that it was commissioned at a capacity use factor of approximately 90% since the start-up, superior to the project one (80%), Unit 1 will reach the limit of 210,000 operating hours at nominal power at the end of 2023, after approximately 26.6 years of operation since the start-up, aproximately 3,4 years before reaching the maximum life span estimated for 30 years, on maintaining the a capacity factor similar to the one reached until the present time, for the rest of the period. The operation, at a capacity factor higher by 10 percentage points was possible due to the project improvement implemented in time as well as the judging method of operation and maintenance.

In this context, SNN analyzed the international experience and practice from other nuclear units type CANDU 6 and identified the opportunity of extending the number of operating hours beyond the 210,000 provided by the project, under nuclear safety conditions and efficiency in operation.

Periodical studies and inspections regarding the behavior in time of the components of Unit#1 and regarding the monitoring of degrading mechanisms associated to „time – limiting" components, respectively reactor's pressure tubes, allowed, at the end of the year 2015, for Candu Energy to estimate as life expectancy for these at Cernavoda NPP Unit#1 to reach at least 220,000 – 230,000 operating hours at nominal power.

The extension of the number of initial operating hours of Unit 1, entails, first of all, the performance of certain studies and analysis, resulting the number of operating hours at nominal power to be reached by the unit, by fully complying with the requirements and standards of nuclear security.

A longer operating period has positive effects on the preparation and development of refurbishment works by:

- extending the accumulation period by the company for its own funds necessary for the project;
- a better preparation of the project and a better organization of works to be developed during the interruption.

The extension of the operating period for the unit after over 210,000 operating hours considered as design hypothesis, does not represent a conditioning of initiating the re-tubing and refurbishment works unless there is the possibility of extension which automatically leads to postponing the effective initiation of interruption for re-tubing/refurbishment.

In September 2017, the SNN shareholders approved the initiation of phase I of the refurbishment strategy of Unit#1 Cernavoda NPP, respectively the phase including the preparation works and termination of all studies, including regarding the extension of the operating hours number, step to be terminated with the submission for approval from the General Meeting of Shareholders (GMS) of the feasibility study.

According to the study regarding the optimum organization of the project the effective refurbishment project is structured in three phases:

Phase I - Project definition:

- project organization activities, at the beginning of 2018 following to operate organizational and logistical changes;
- termination process of support documentation necessary for the preparation of the Feasibility Study including the drafting and submitting for approval of the shareholders, in 2021;
- activities necessary to provide the operation of Unit 1 for a period of 30 years based on the study performed by Candu Energy.

Phase II - Implementation preparation:

- drafting engineering sets related to the project changes;
- procurement of equipment and components with extended manufacturing cycle;
- awarding the engineering, procurement and building contract (EPC);
- obtaining from CNCAN the authorization to start the refurbishment works.

Phase III - Interrupting the unit and effective development of the refurbishment project:

- Unit shutdown and the effective refurbishment of the project, scheduled to develop during December 2026 – December 2028, as the project is implemented with a minimum estimated period of 24 months, [18].

4. Conclusion

The objective of the operators, owners and researchers in the nuclear field is to maintain the CANDU NPP as a safe and reliable means of electricity production in recognition of its role in today's global economy. To achieve this standard, the industry has focused on an effective strategy for PLIM and PLEX. For existing CANDU stations, the program must now be executed in co-operation with the utilities to assure continued good performance of the CANDU 6 units and preservation of the life extension option. Feedback from these programs, the optimized plant inspection and maintenance and the technology watch, will result in a continuous improvement process benefiting existing and future CANDU 6 plant owners and operators.

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